

# FOUNDATIONS ON SHRINKING AND SWELLING SOILS

## (Prediction of Movement, Construction Issues)

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by

Jean-Louis Briaud, Sangho Moon, Xiong Zhang

Department of Civil Engineering,  
Texas A&M University, College Station,  
Texas 77843-3136, USA

## **ACKNOWLEDGEMENTS**

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- **ENVIRONMENTAL SOIL STABILIZATION LTD.**

**Russ Scharlin**

**Johny Sherwood**

- **SPENCER J. BUCHANAN PROFESSORSHIP**

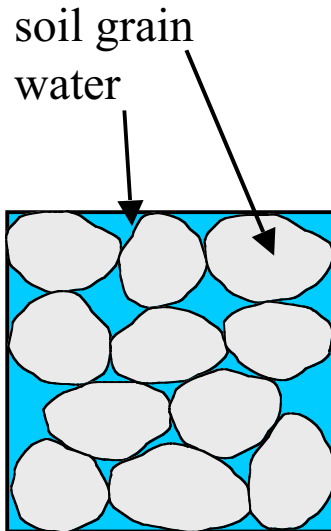
- **GILES ENGINEERING ASSOCIATES INC.**

**Doug Dayton**

# OUTLINE

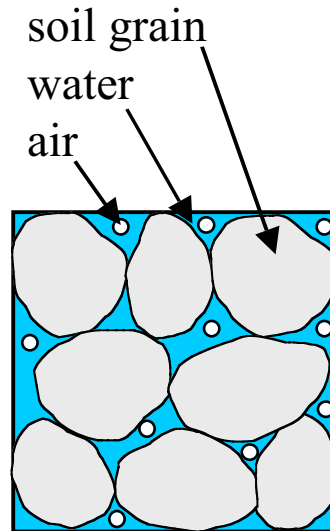
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- **FUNDAMENTAL BEHAVIOR**
- **SHRINK TEST – WATER CONTENT METHOD**
- **CASE STUDY**
- **SMART FOUNDATION**



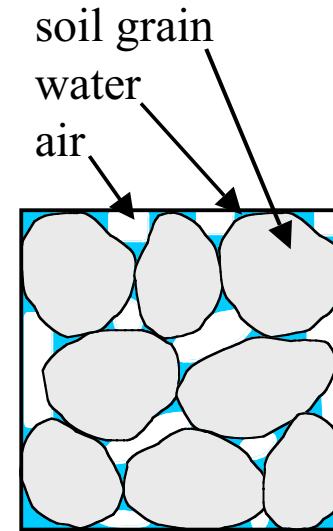
**Saturated**

$$\begin{aligned}
 u_w &\neq 0 \\
 u_a &= 0 \\
 \sigma' &= \sigma - u_w
 \end{aligned}$$



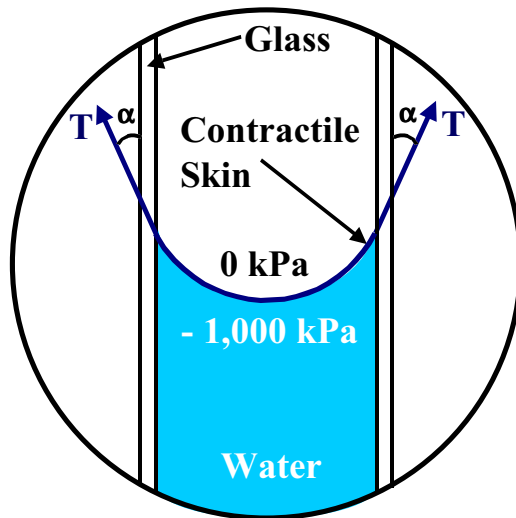
**Occluded Air**

$$\begin{aligned}
 u_w &= u_a \\
 \sigma' &= \sigma - u_w
 \end{aligned}$$



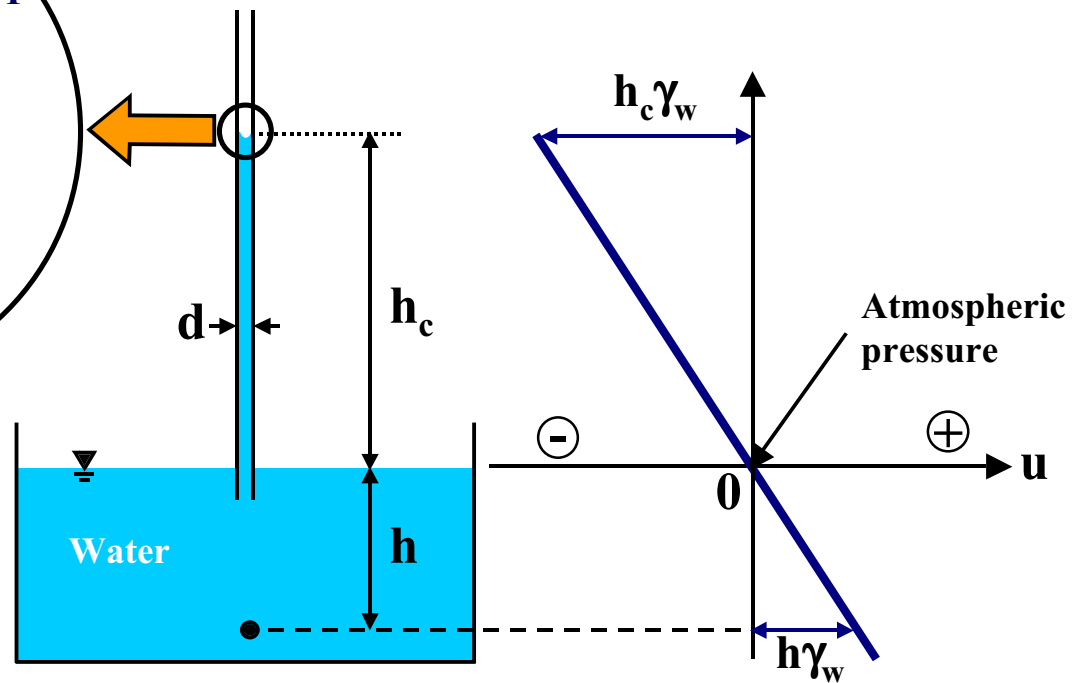
**Continuous Air**

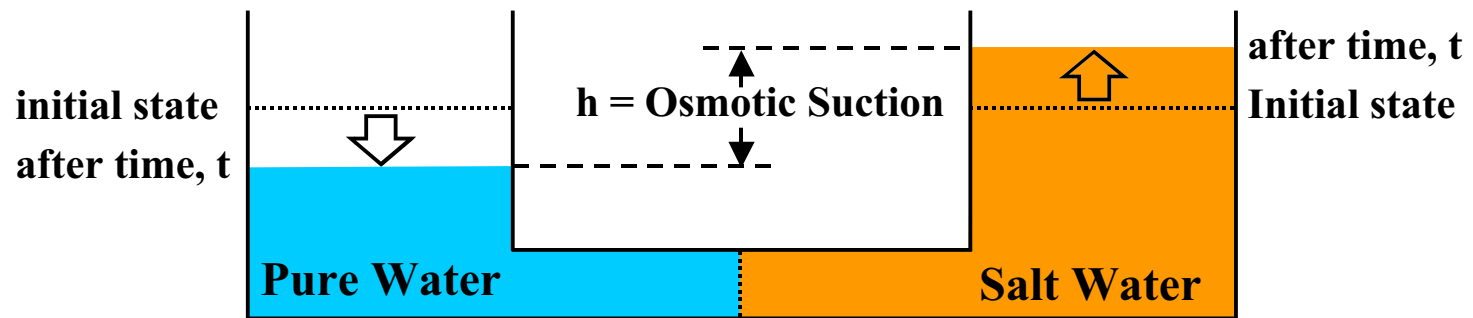
$$\begin{aligned}
 u_w &\neq 0 \\
 u_a &= 0 \\
 \sigma' &= \sigma - \alpha u
 \end{aligned}$$



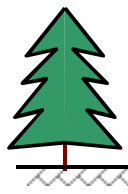
$$h_c = \frac{4 T \cos \alpha}{d \tilde{\alpha}_w}$$

where  $T = 72 \text{ mN/m}$

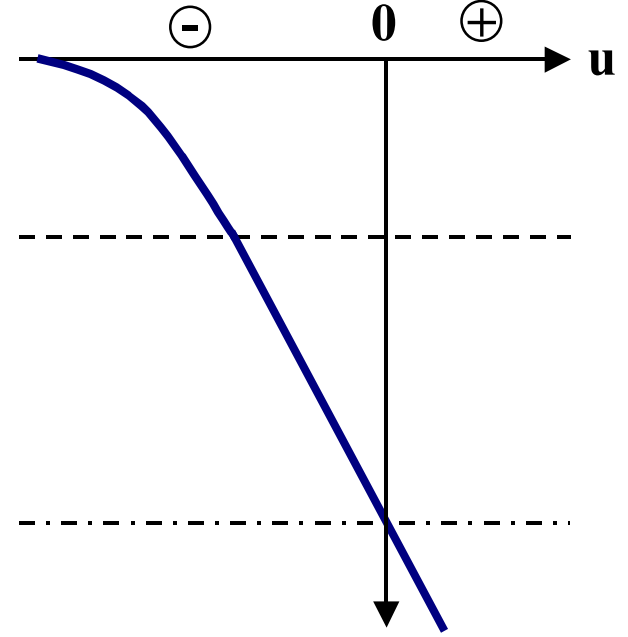




Water State	Examples	Suction			Degree of Saturation	Water Content	Swell	Shrink
		pF	cm	kPa				
Suction  Tension  ↑  ↓	Oven Dry	7	$-10^7$	$-10^6$	0	0	YES  ↑  ↓  NO	NO  ↑  ↓  YES
	Air Dry	6	$-10^6$	$-10^5$				
	Shrinkage Limit	4	$-10^4$	$-10^3$	Near 100 %	8 to 15 %		
	Field Capacity Swell Limit	2	$-10^2$	$-10^1$		25 to 50 %		
Compression  ↓  ↑		0	0	0	100 %			
	Large River		$10^3$	$10^2$				
	Deepest Offshore Platforms		$10^5$	$10^4$				
	Bottom of Deepest Ocean		$10^9$	$10^8$				

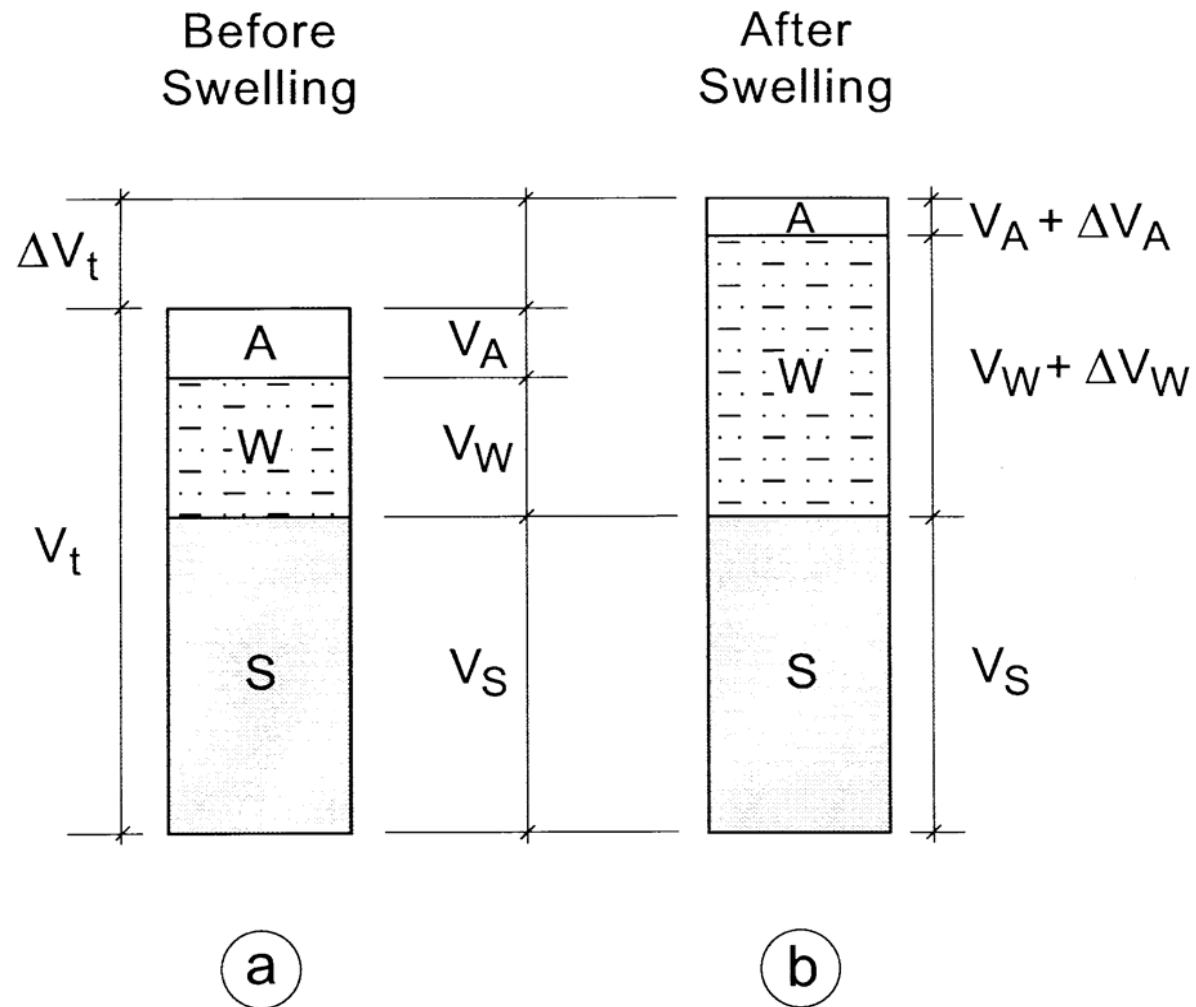


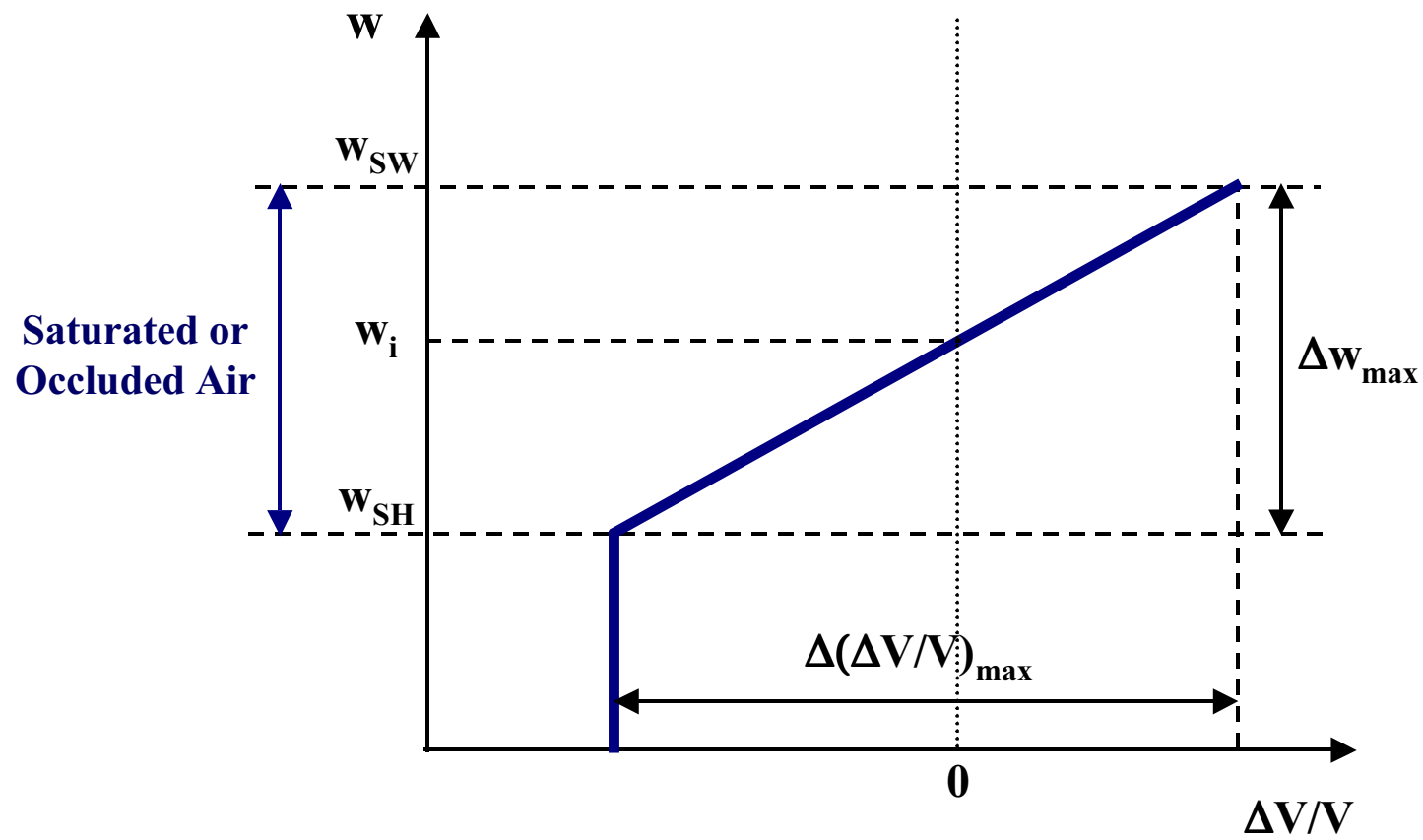
Soil State	Swell	Shrink
Unsaturated	Yes	No
Saturated	Yes	Yes
<div style="display: flex; align-items: center; justify-content: center;"> <span style="margin-right: 5px;">∇</span> <span style="color: blue;">GWL</span> </div>		
Saturated	No	Yes



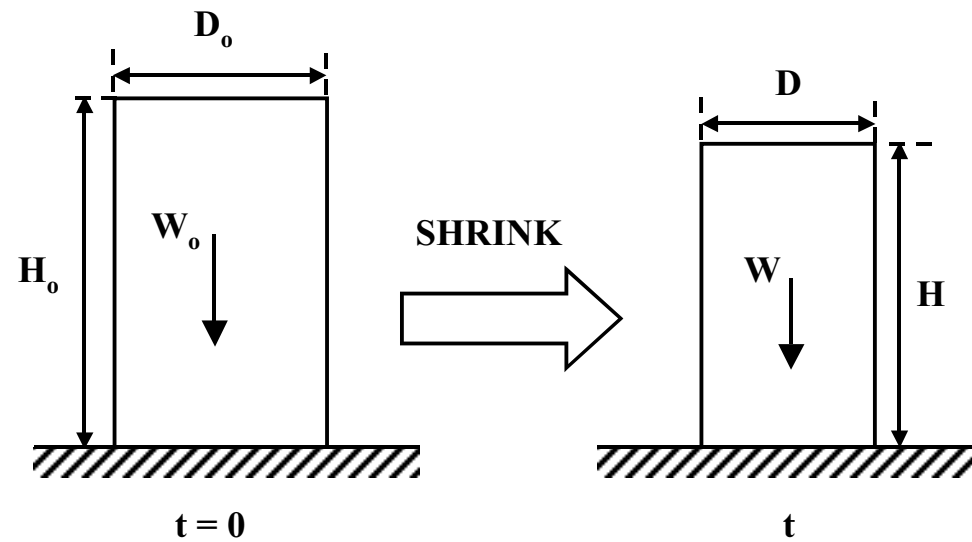


# PHASE DIAGRAMS





# SHRINK TEST PARAMETERS

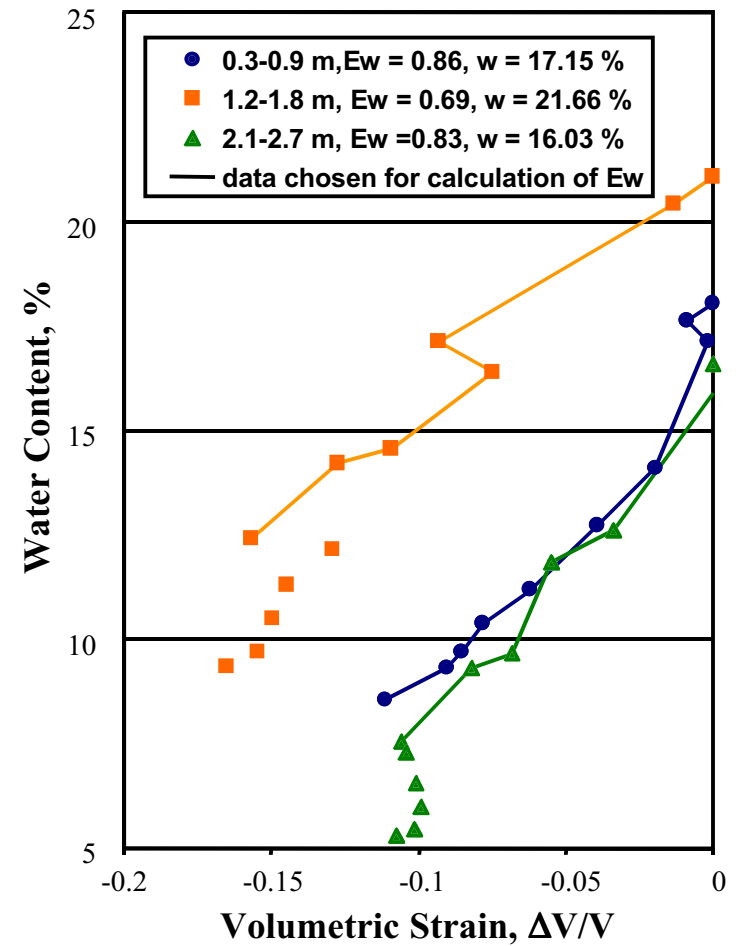


# SHRINK TEST

## Shrink Test

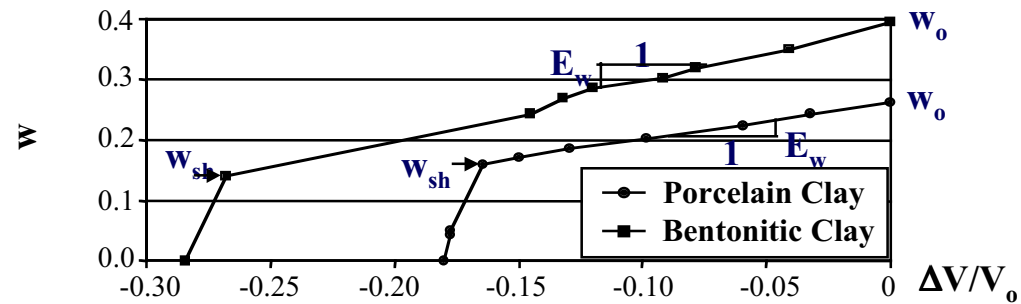
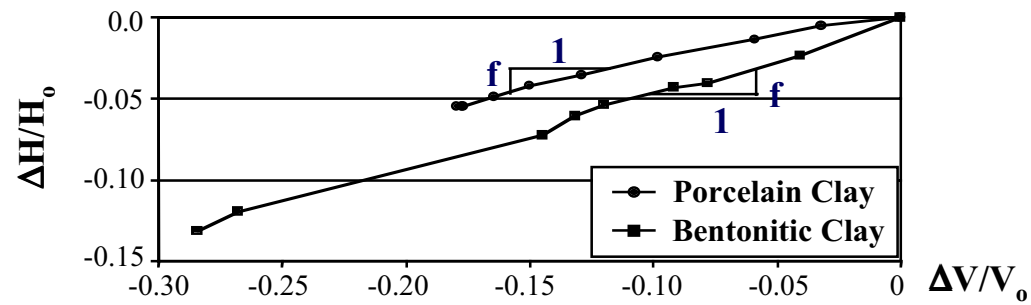
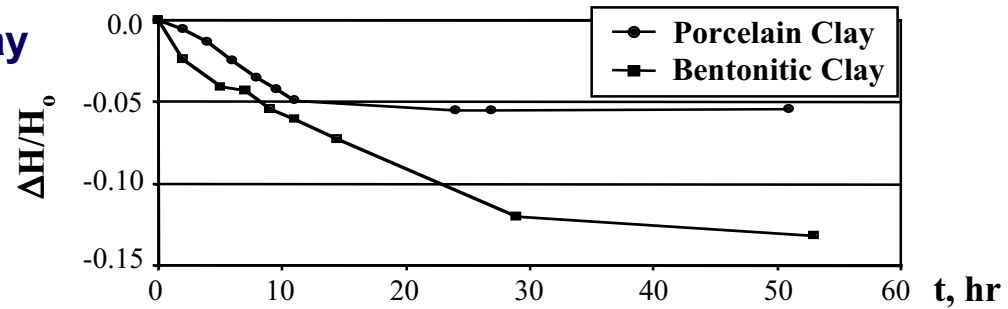


## Shrink Test Example (B/RF1/6)



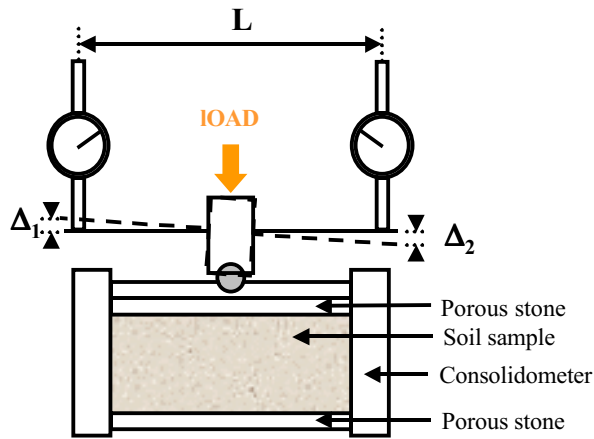
# SHRINK TEST RESULTS (1)

## Porecelain Clay and Bentonite Clay

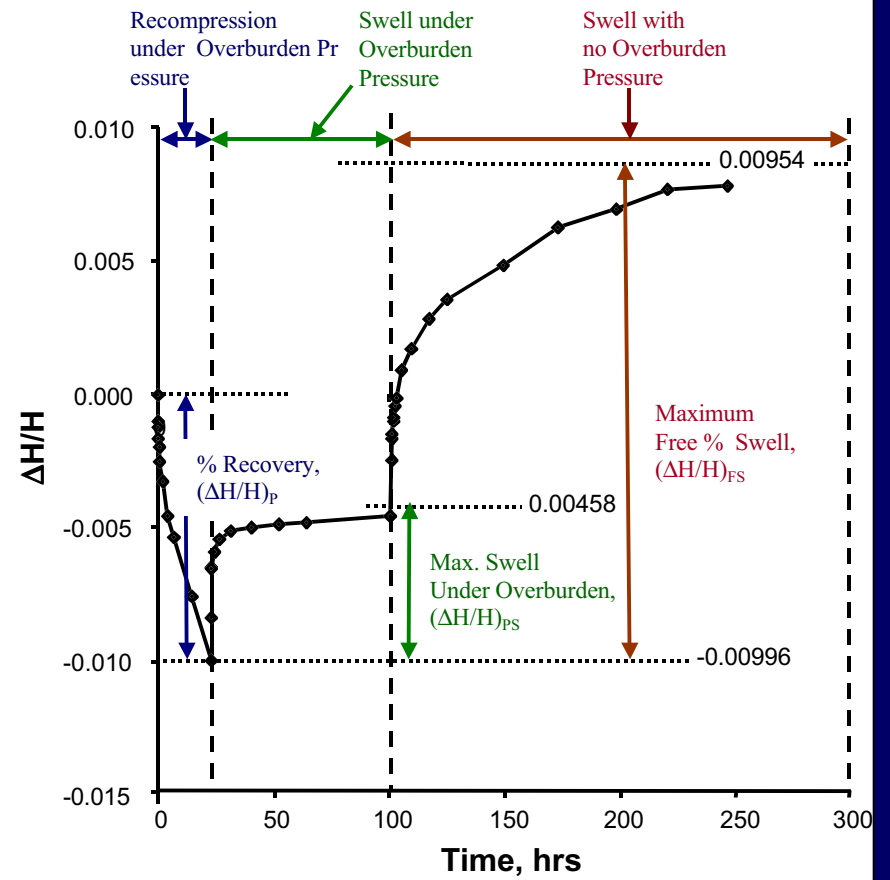


# SWELL TEST

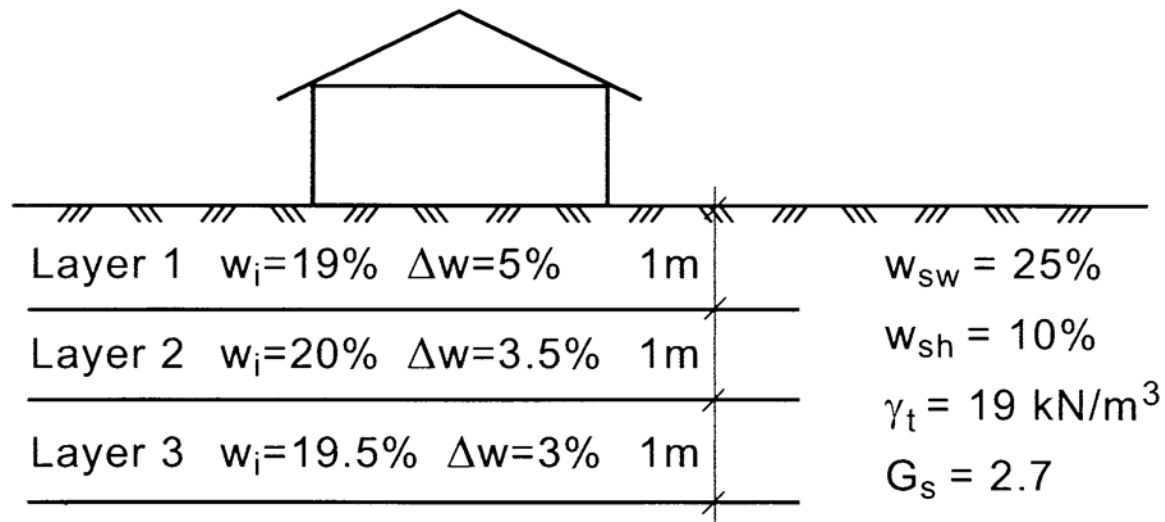
## Swell Test



## Swell Test Example (B/RF1/6 0.3–0.9 m)



## EXAMPLE OF THE PREMISSE METHOD



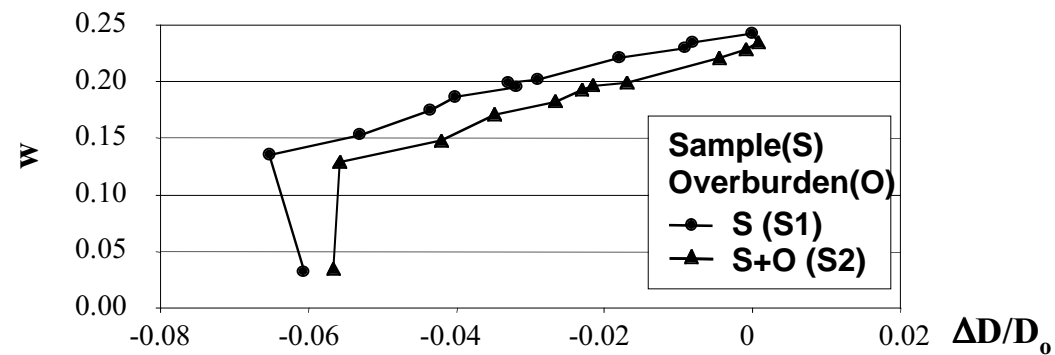
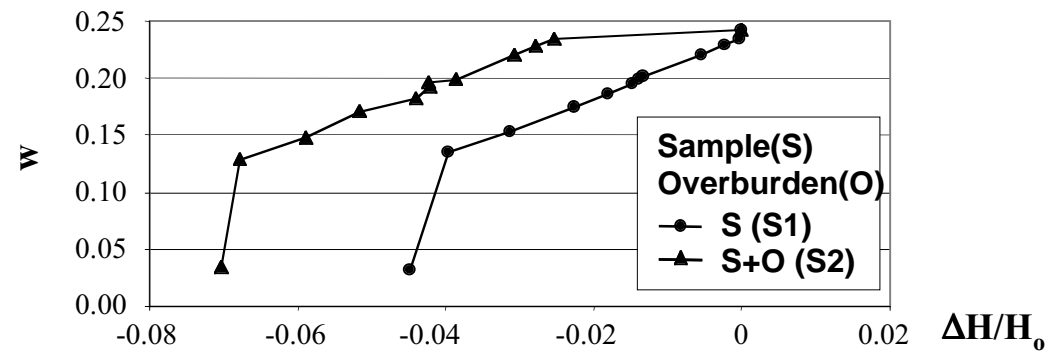
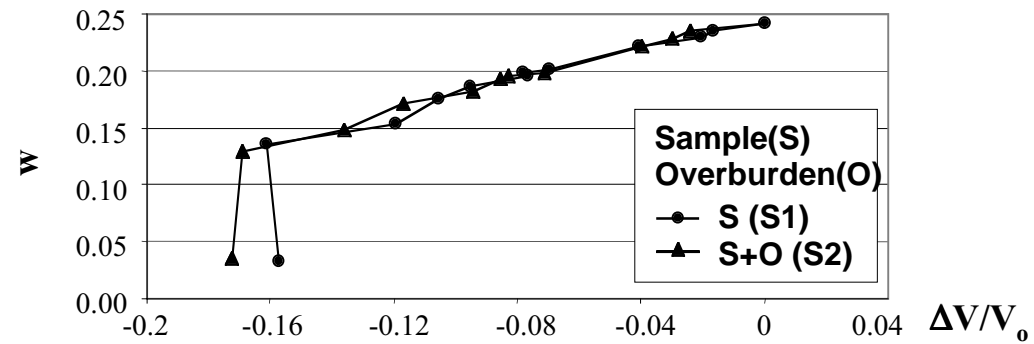
	w	s	n	$\Delta w$	$\frac{\Delta V_w}{V_t}$	$\frac{\Delta V_a}{V_t}$	$\frac{\Delta V_t}{V_t}$	$\Delta H^*$ (mm)
Layer 1	0.19	0.78	0.40	0.05	0.0821	-0.0235	0.0586	58.6
Layer 2	0.20	0.80	0.40	0.035	0.0560	-0.0149	0.0411	41.1
Layer 3	0.195	0.79	0.40	0.03	0.0486	-0.0134	0.0352	35.2

\*Using  $H_t$  = layer thickness and  $\alpha = 1$ .

$\Delta H_t = 134.9 \text{ mm}$

# SHRINK TEST RESULTS (3)

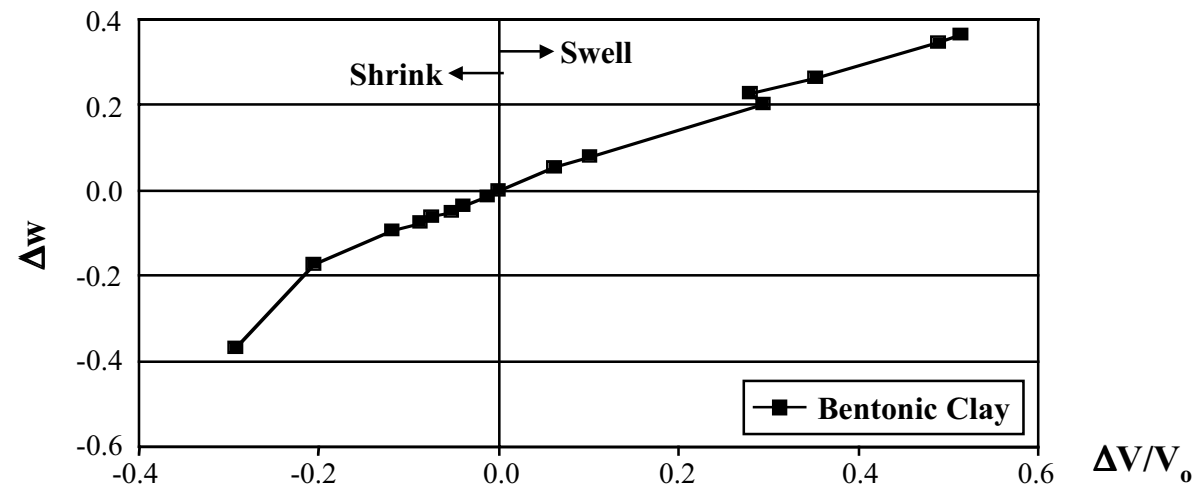
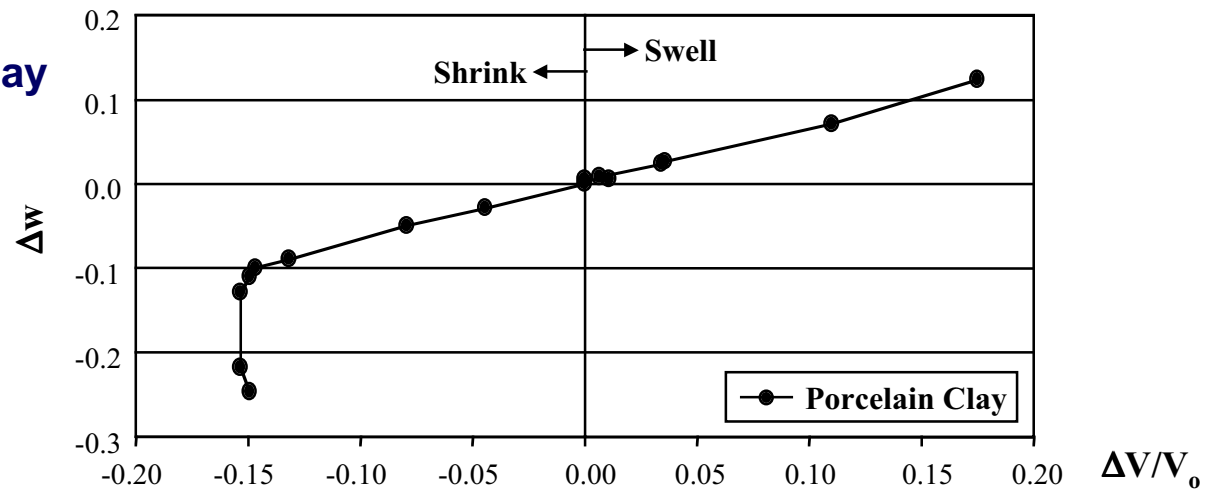
## Influence of Vertical Pressure





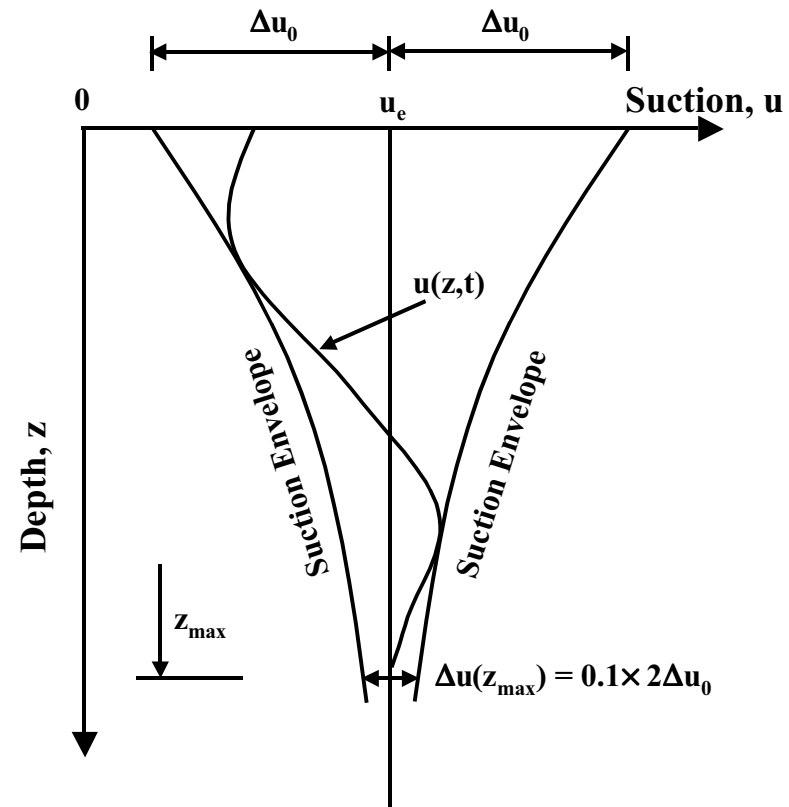
# SHRINK AND SWELL TEST RESULTS

## Porecelain Clay and Bentonite Clay



# SUCTION VARIATION WITH DEPTH

After Mitchell (1979)



After Mitchell (1979)

$$\Delta u(z) = 2 \Delta u_0 \exp \left( - \left( \frac{z}{T_0 \alpha} \right)^{0.5} \right)$$

$$\Delta w = f(\Delta u) \quad \text{characteristic curve}$$

$$z_{\max} = 1.3 (T_0 \alpha)^{0.5}$$

where  $\Delta u$  = change in suction at depth  $z$

$\Delta u_0$  = change in suction at ground surface

$T_0$  = period of weather cycle

$\alpha$  = diffusion coefficient

$z$  = depth below ground surface

$\Delta w$  = change in water content

$z_{\max}$  = maximum depth of water content change

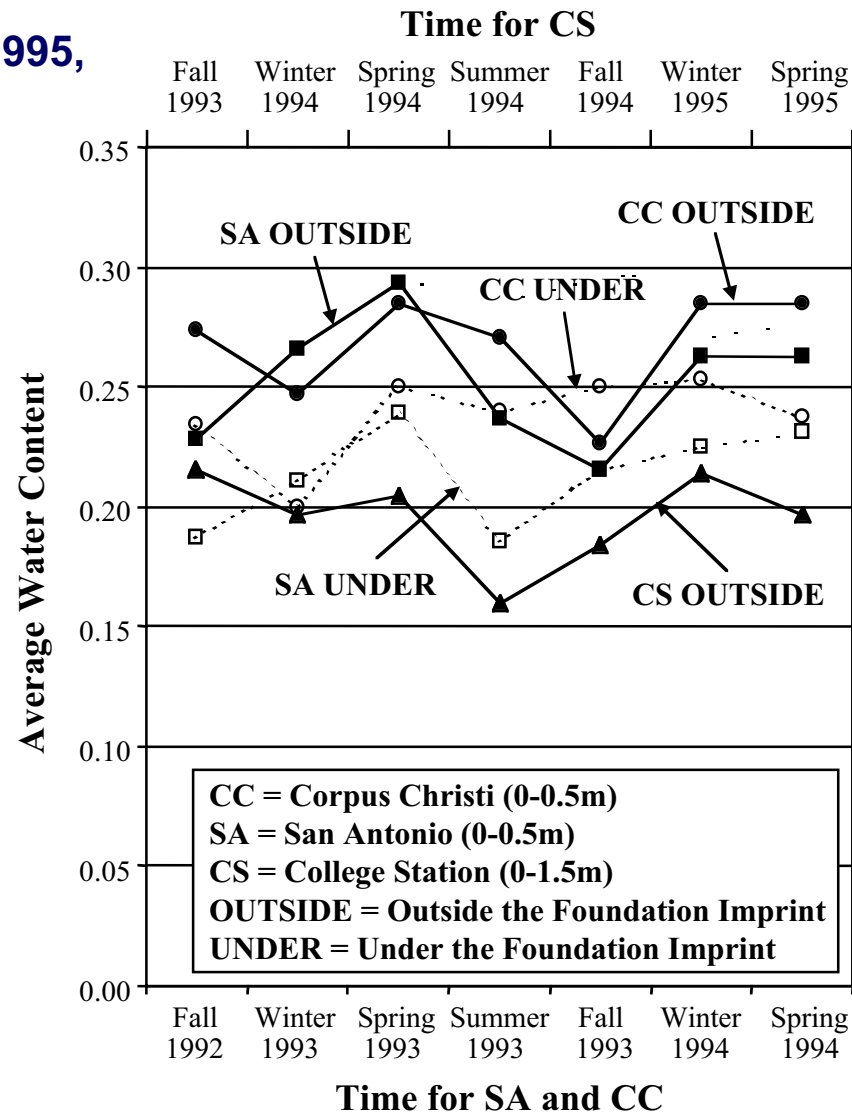
After Styron et al. (2001)

$$LI \times LL (\%) = \pm 30$$

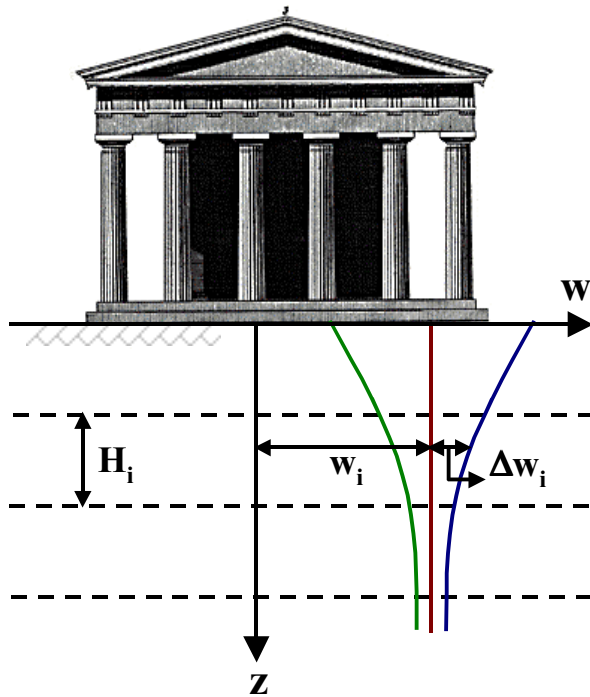
$$\ddot{A}_w = 0.6 (PI/LL)$$

# WATER CONTENT VARIATION AS A FUNCTION OF TIME

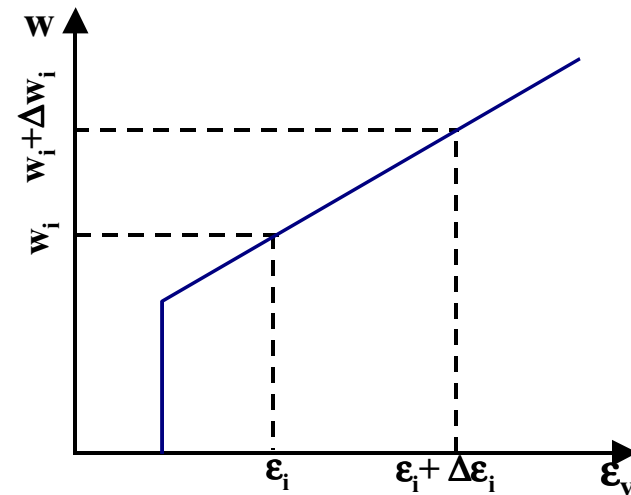
From Posey, Briaud, 1995,  
Woodfin, Briaud, 1997



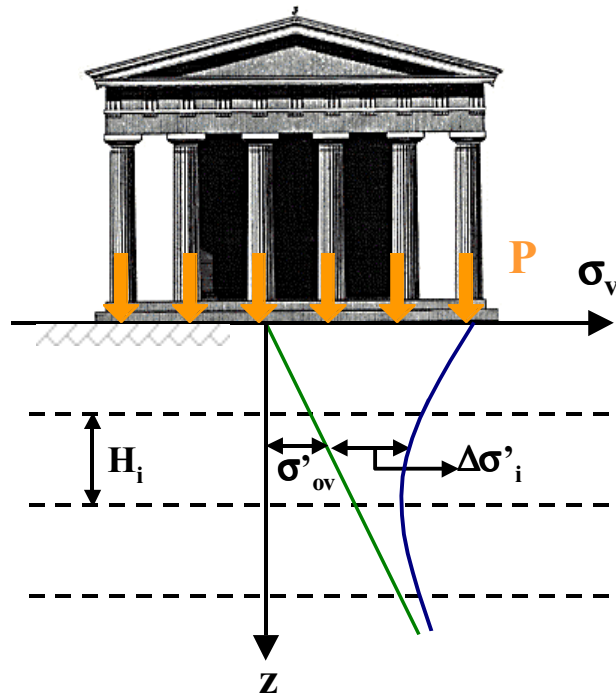
# MOISTURE INDUCED MOVEMENT



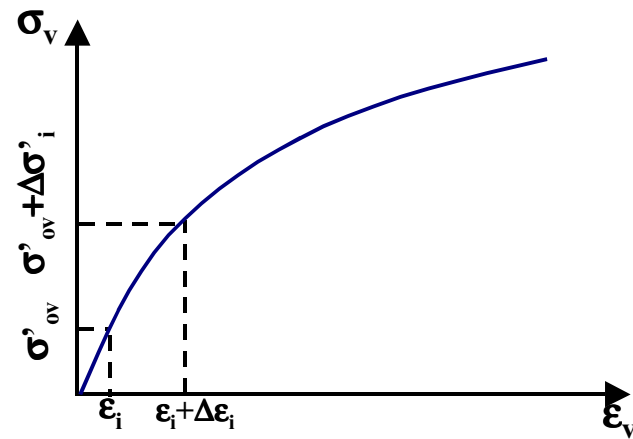
$$S = \sum H_i \Delta \epsilon_i = \sum H_i f \frac{\Delta w_i}{E_{w_i}}$$



# WEIGHT INDUCED SETTLEMENT

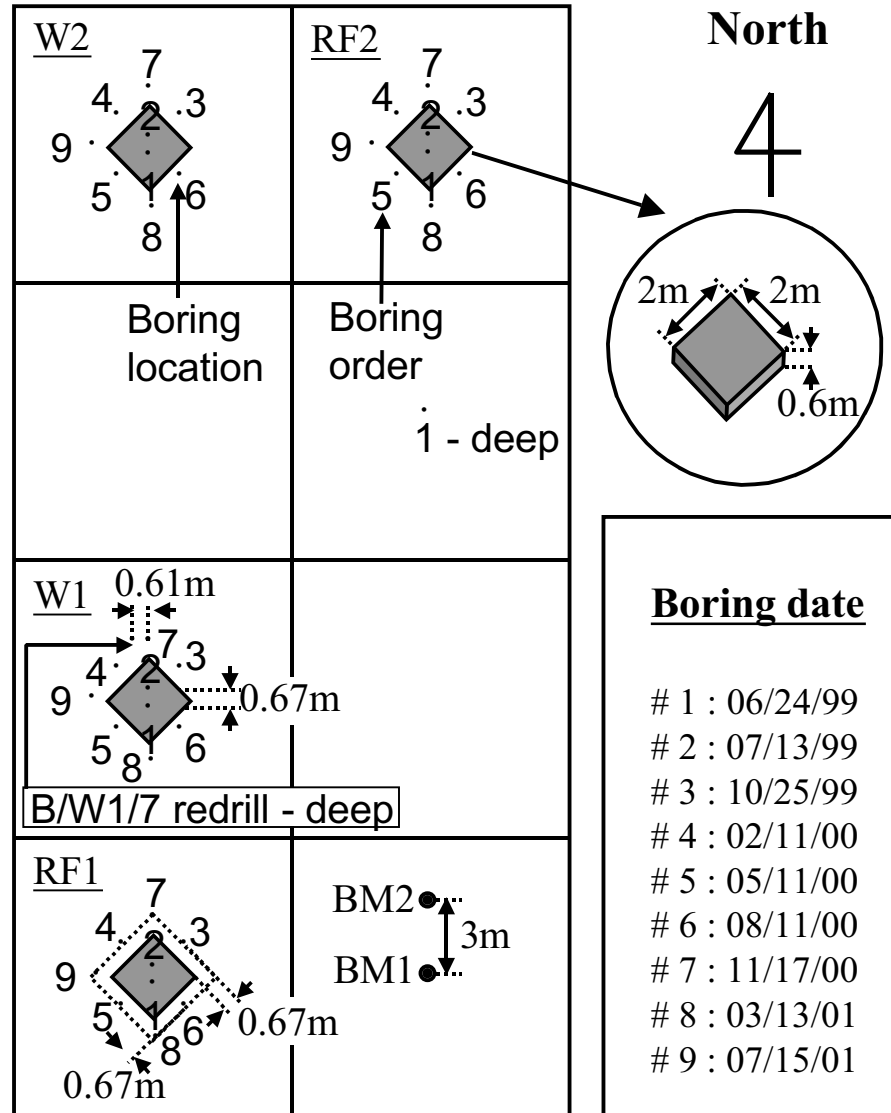


$$S = \sum H_i \Delta\epsilon_i = \sum H_i \frac{\Delta\sigma_i}{E_i}$$



# PLAN VIEW OF THE SITE

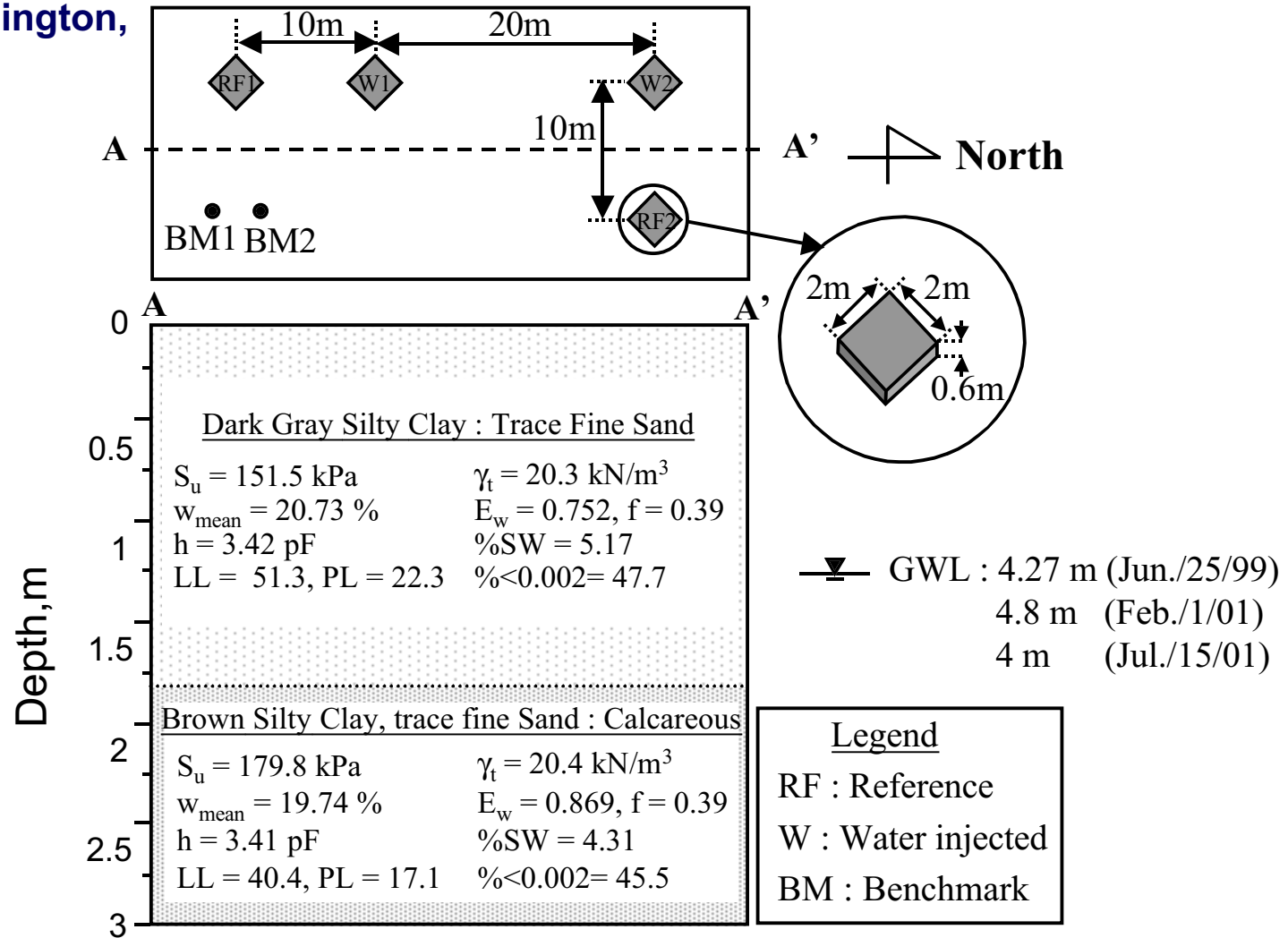
Site in Arlington, Texas





# SOIL STRATIGRAPHY

Site in Arlington, Texas

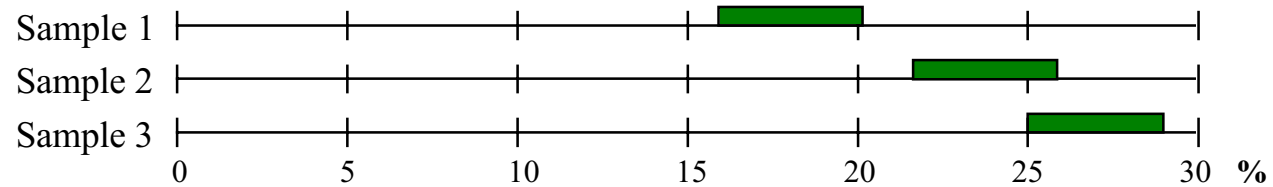




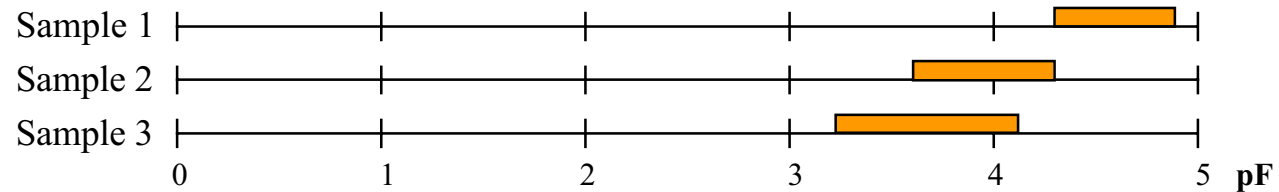
# GARNER'S STUDY (1999)

3 samples at 3 water contents sent to 5 laboratory.

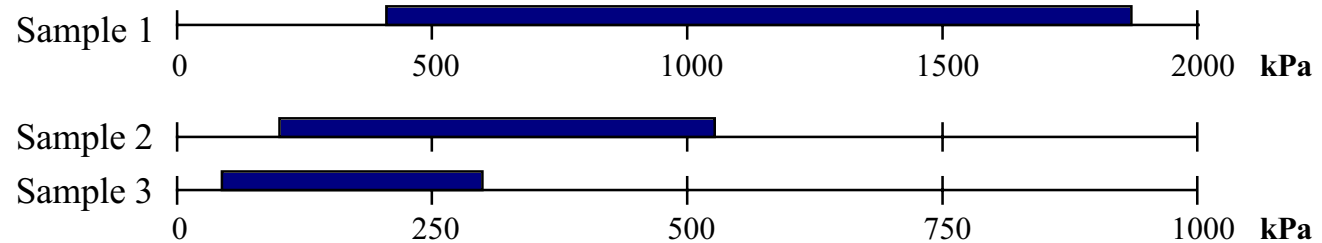
## Water Content, %



## Suction, pF

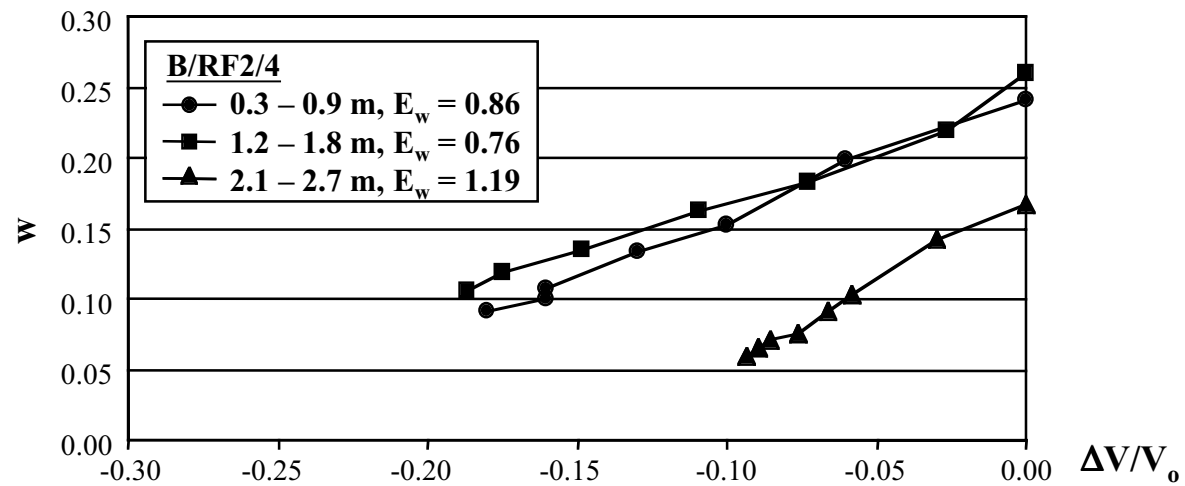
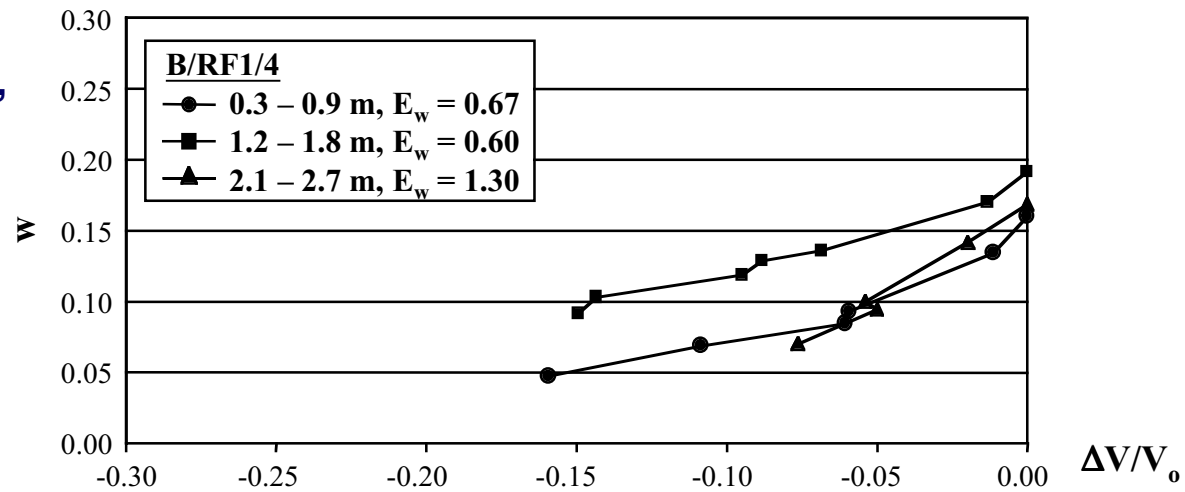


## Suction, kPa



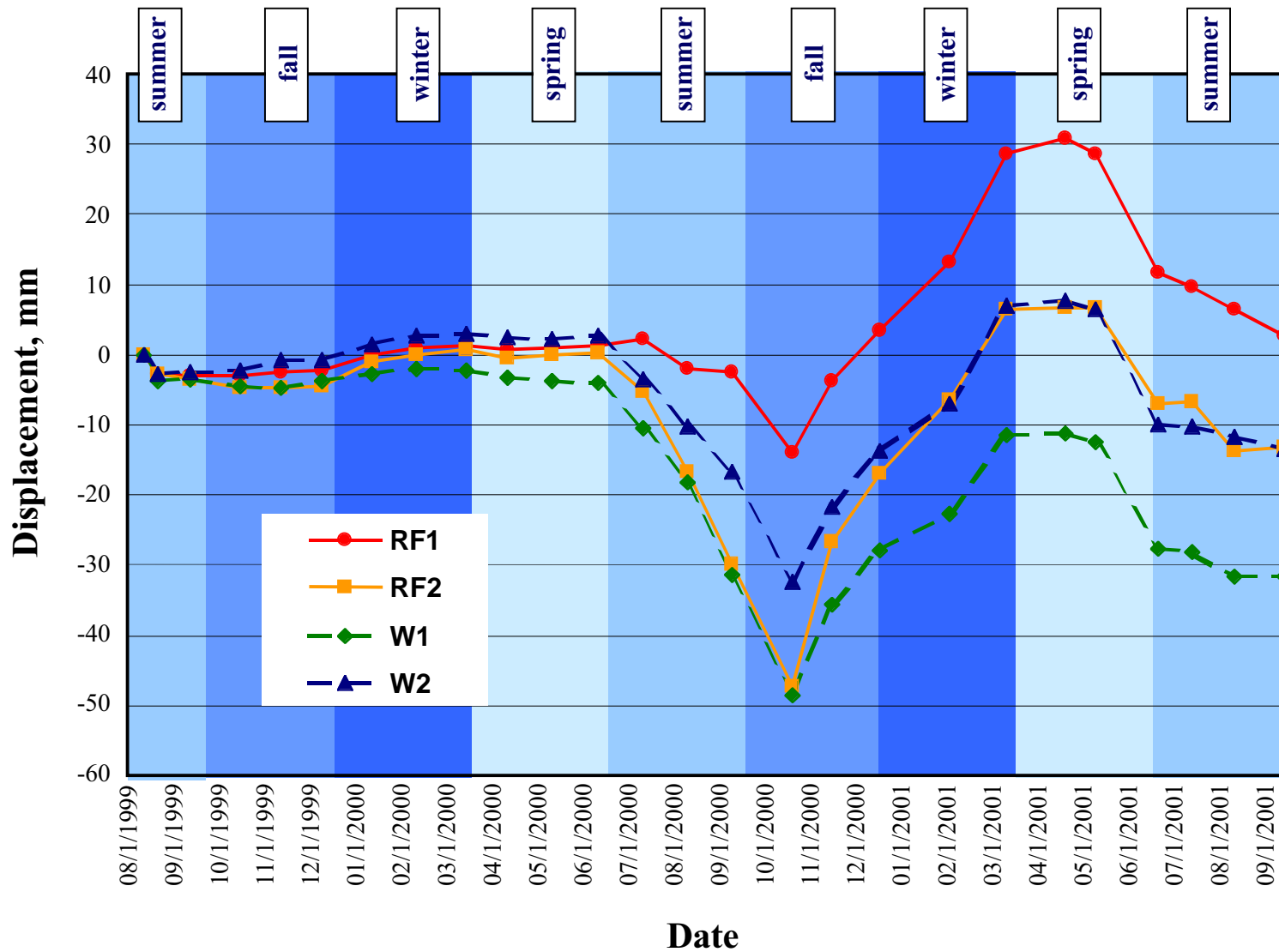
# SHRINK TEST RESULTS (2)

Three Samples  
From Arlington,  
Texas

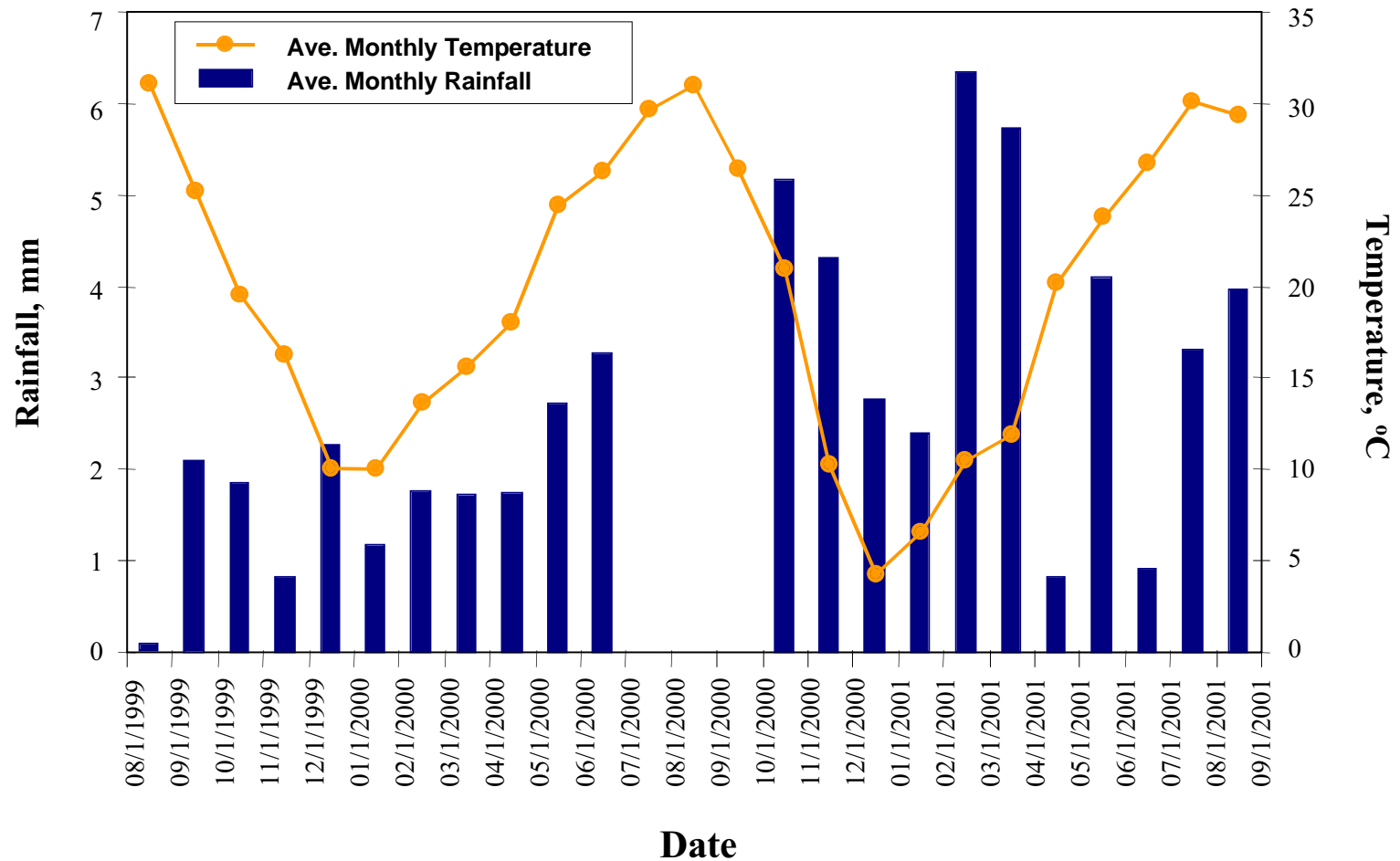




# FOOTING MOVEMENT OVER TWO YEARS

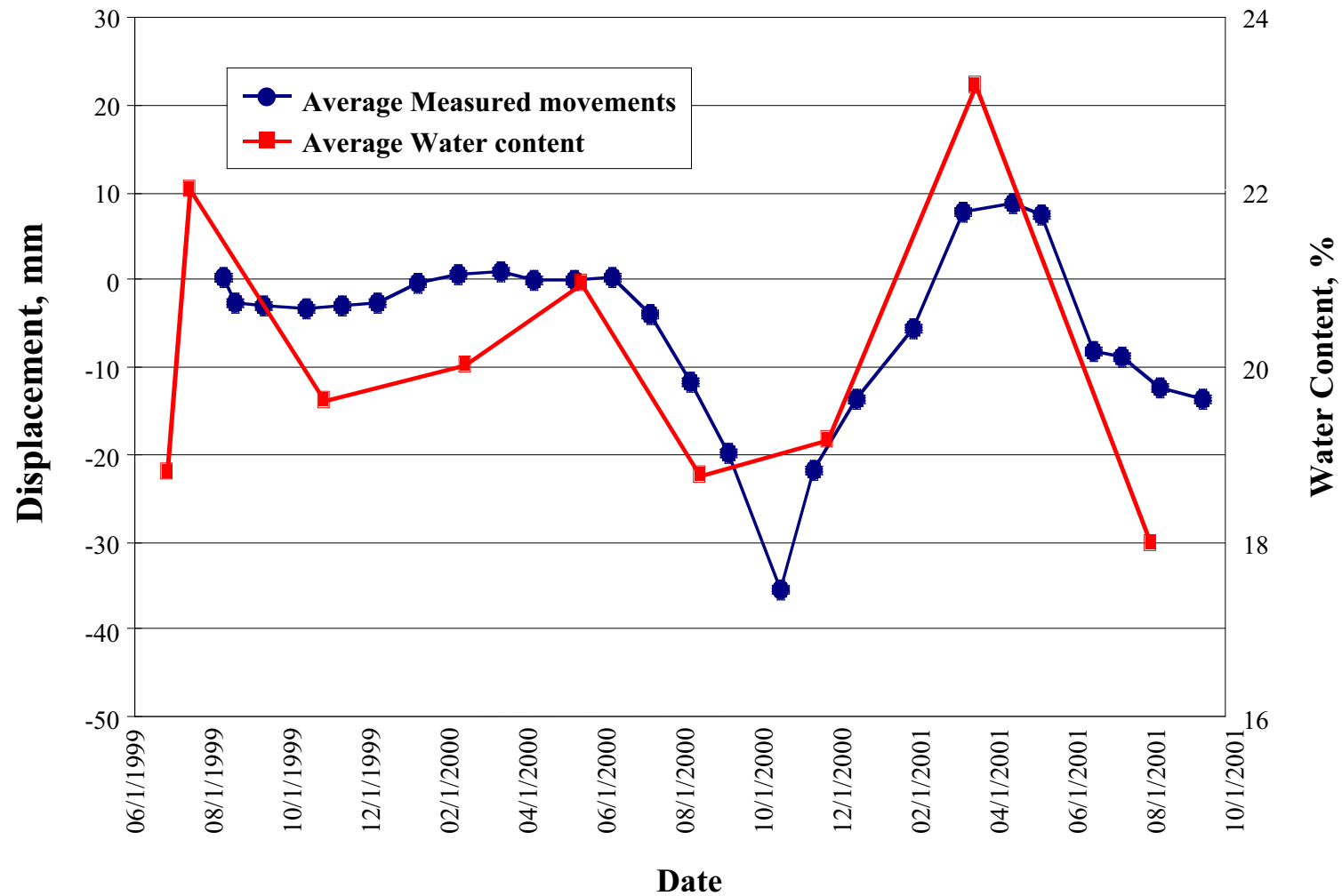


# RAINFALL AND TEMPERATURE



# WATER CONTENT VARIATION AND MOVEMENT

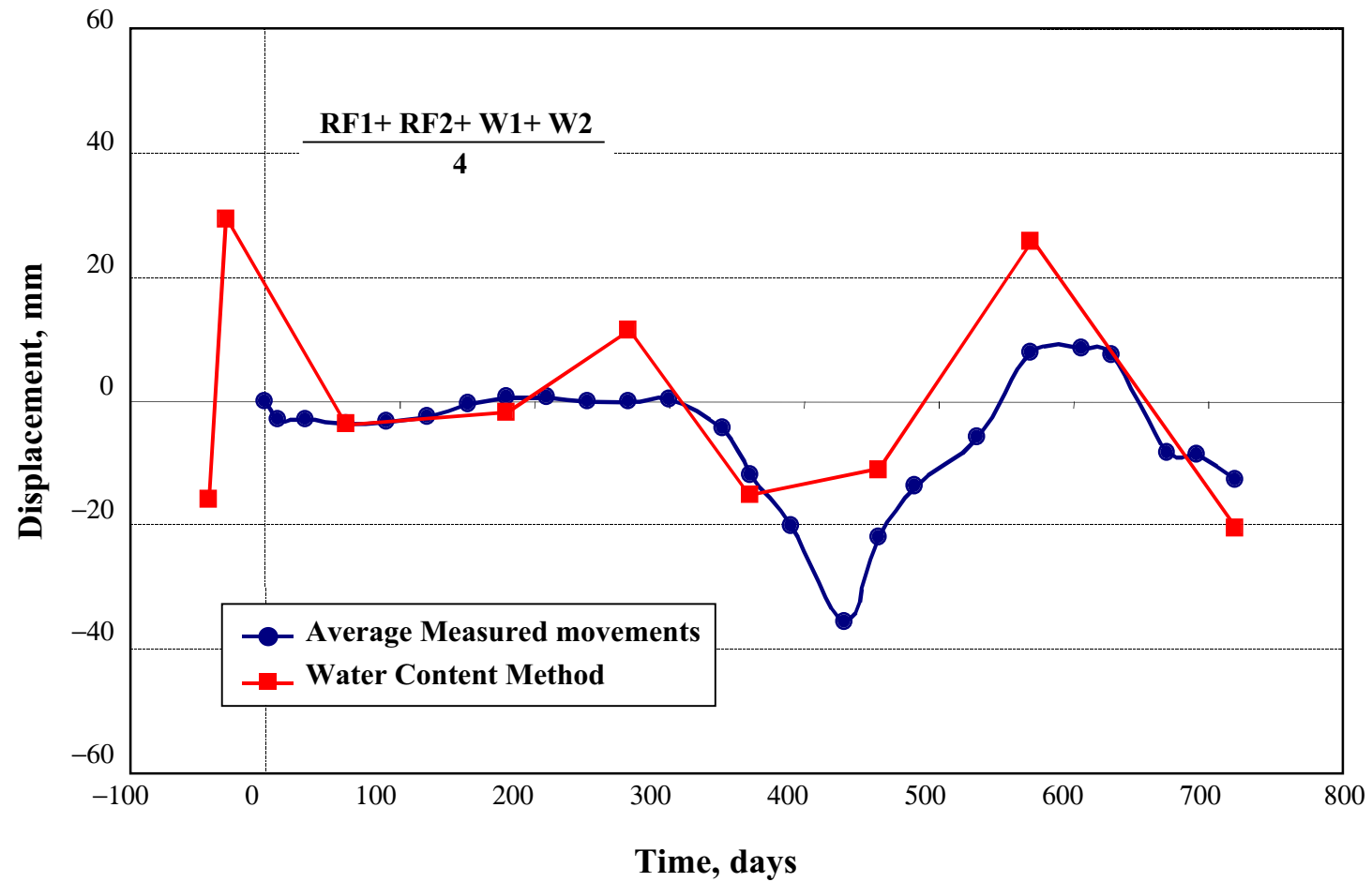
Average of 4 Footings at a site in Arlington, Texas



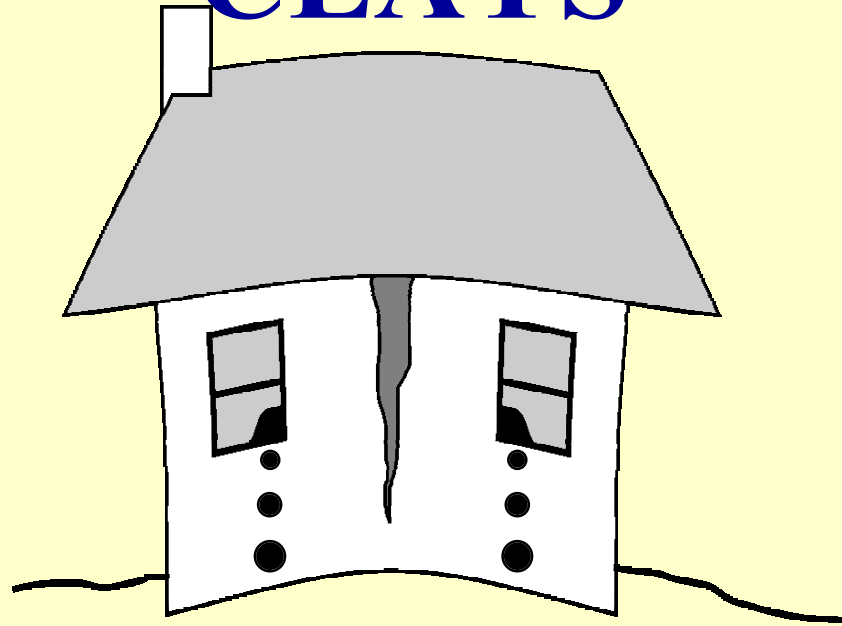


# PREDICTED AND MEASURED MOVEMENTS

Average of 4 Footings at a site  
in Arlington, Texas



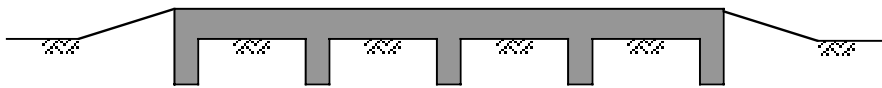
# HOUSES ON EXPANSIVE CLAYS



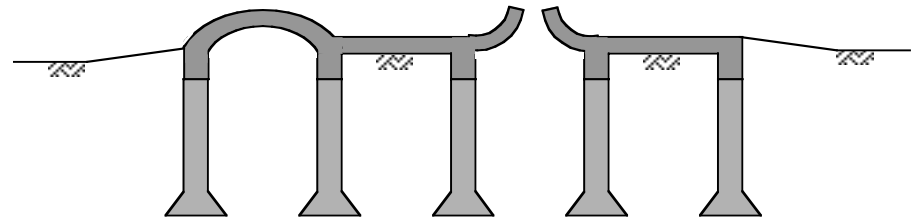
**MOST EXPENSIVE  
NATURAL HAZARD  
IN THE COUNTRY**

# FOUNDATION SOLUTION

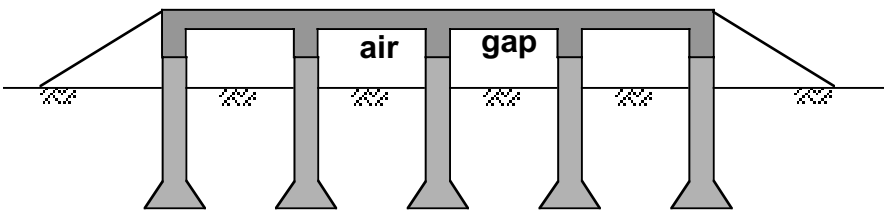
• Stiffened Slab on Grade



• Stiffened Slab on Grade & on Piers



• Elevated Structural Slab on Piers



• Thin Post Tensioned Slab

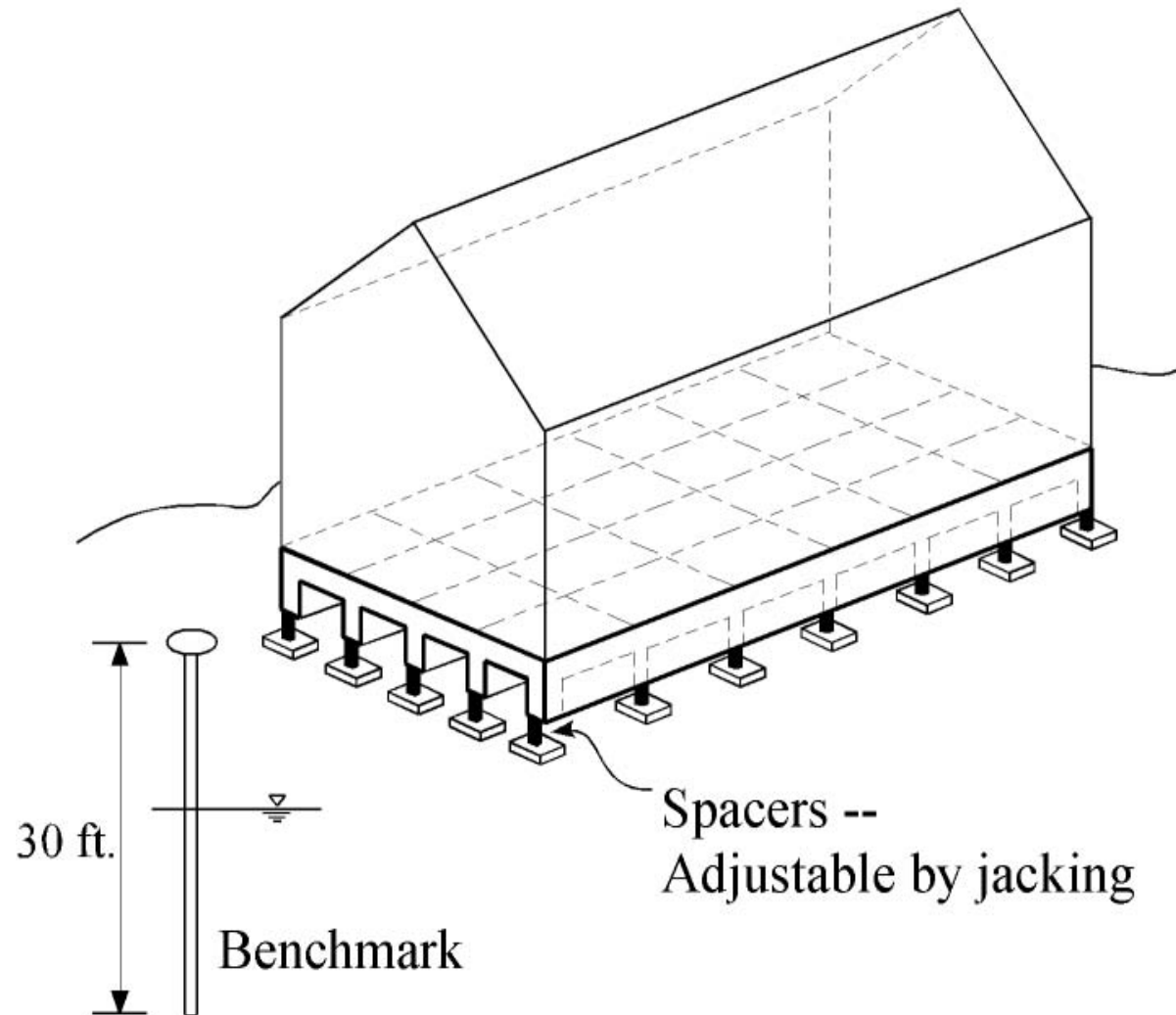


# **HOUSES ON EXPANSIVE CLAYS**

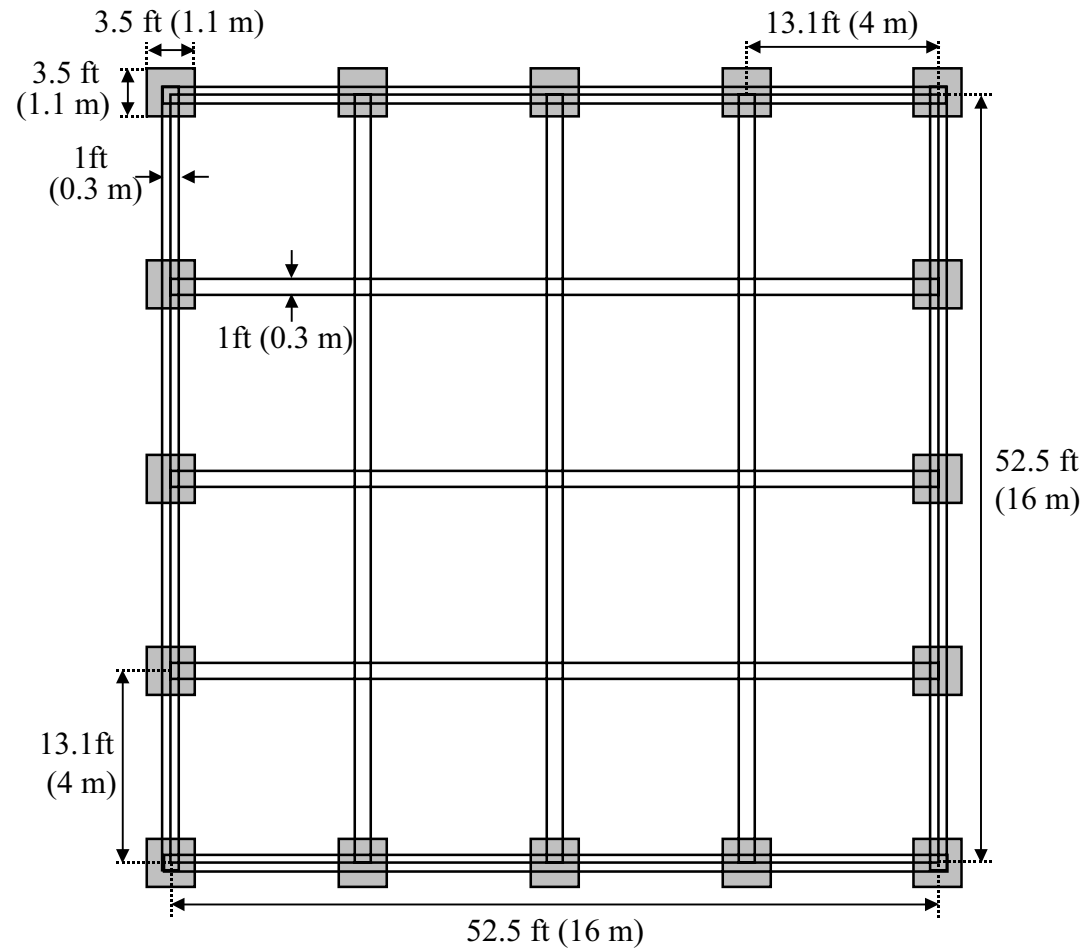
**VERY DIFFICULT TO PREDICT  
THE SOIL MOVEMENT  
(WEATHER, VEGETATION, DRAINAGE)**

**MUCH EASIER TO DESIGN  
AN ADJUSTABLE FOUNDATION**

# SMART FOUNDATION

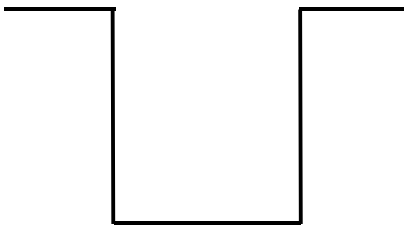


# SMART FOUNDATION

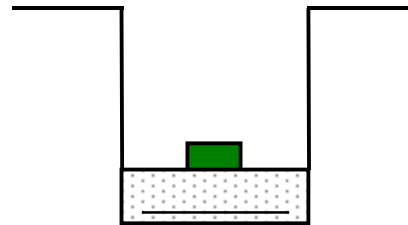


# SMART FOUNDATION CONSTRUCTION

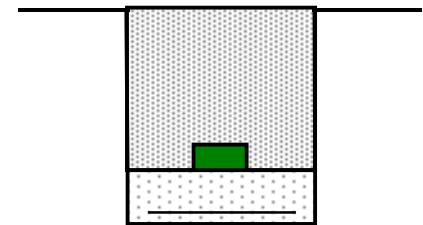
Make Cavity



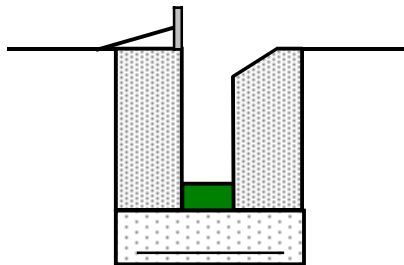
Cast Footing & Place Spacer



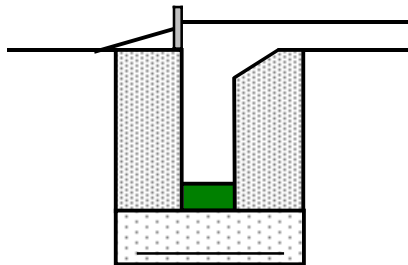
Back Fill



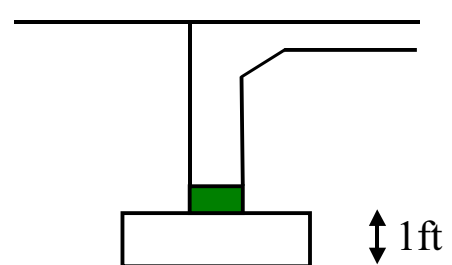
Excavate Trench



Cast Beam



Finish



## COST COMPARISON

### Conventional Waffle Slab

16 m × 16 m × 0.1 m Slab on Grade with  
0.9 m deep × 0.3 m thick Beams every 4 m

\$24,000

### Smart Foundation

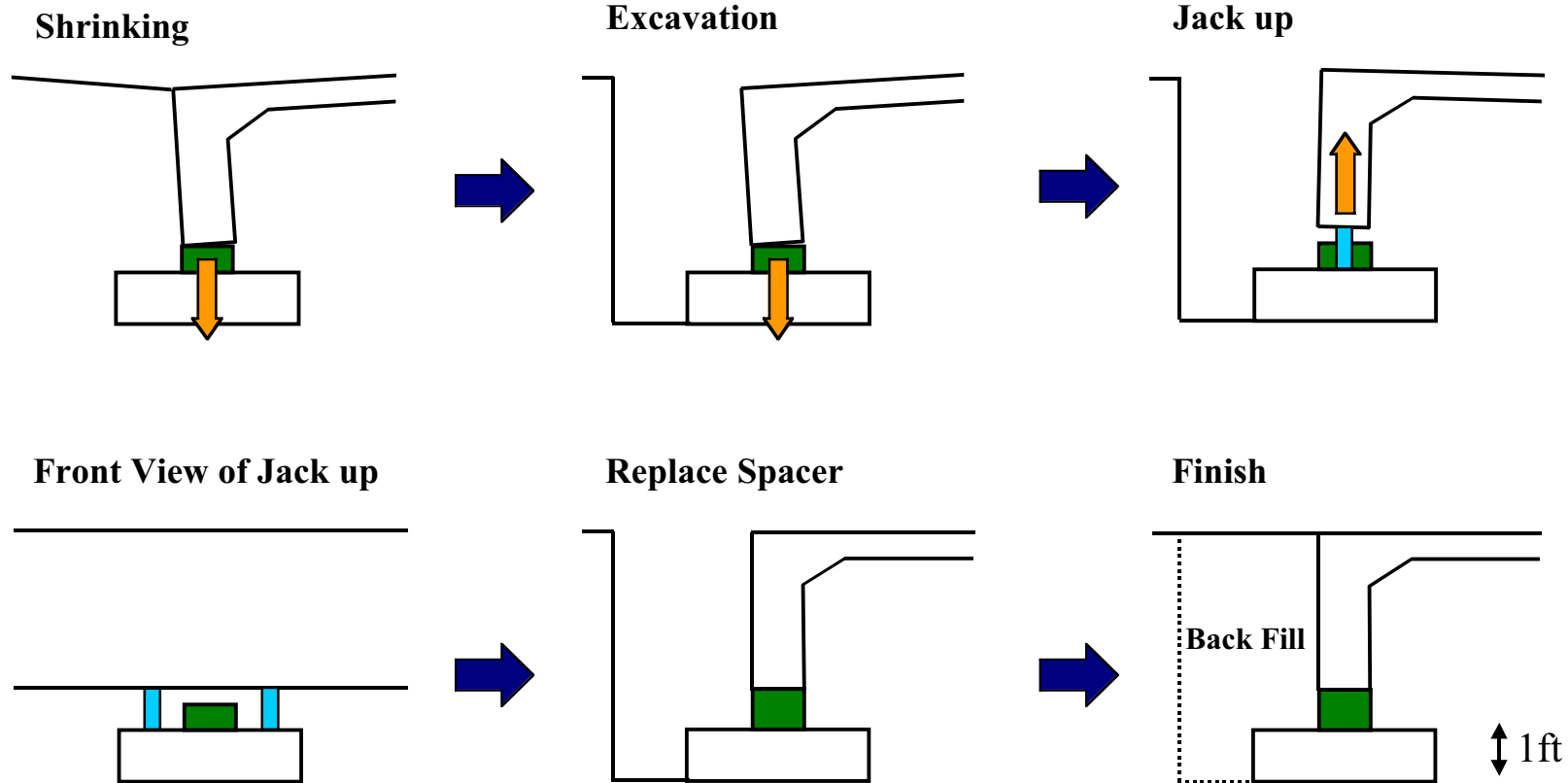
16 m × 16 m × 0.1 m Slab on Grade with  
0.9 m deep × 0.3 m thick Beams every 4 m  
and 1 m × 1 m × 0.3 m Footings

\$26,200

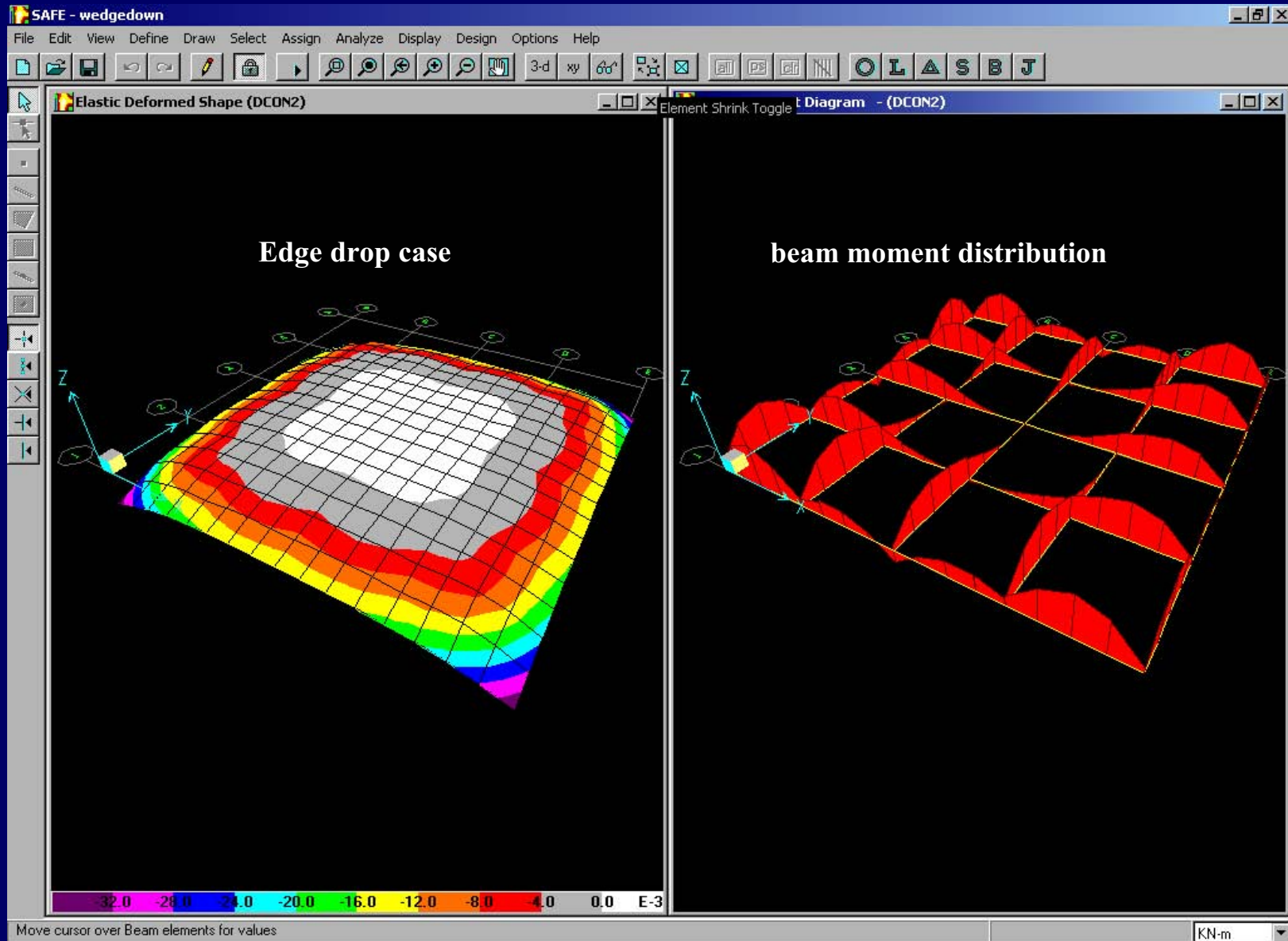
~ 10 % Increase in Cost



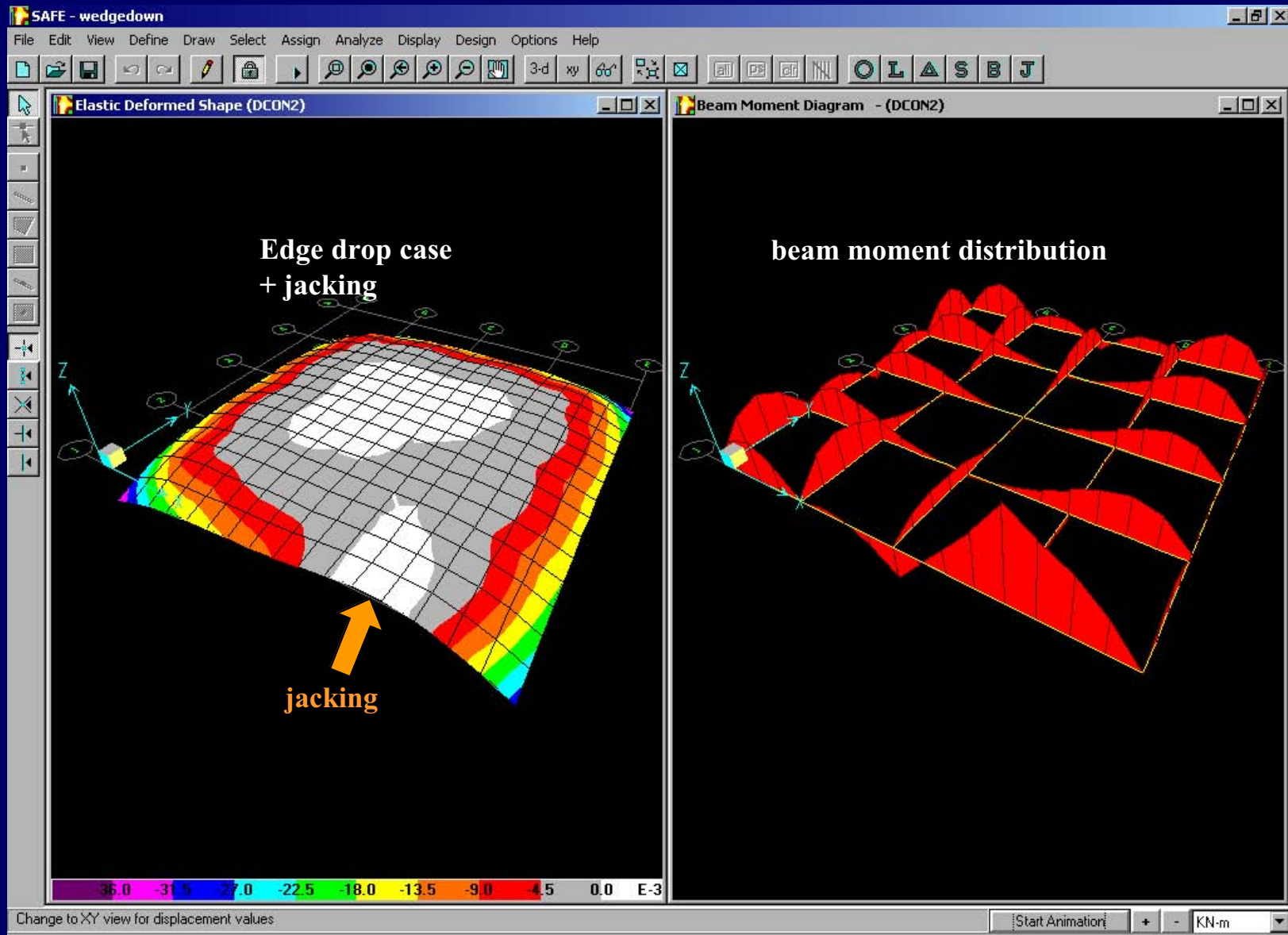
# SMART FOUNDATION ADJUSTMENT



# FOUNDATION ANALYSIS BY SAFE



# FOUNDATION ANALYSIS BY SAFE



## CONCLUSIONS

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- **FUNDAMENTAL BEHAVIOR**
- **SHRINK TEST – WATER CONTENT METHOD PROPOSED**
- **SHRINK TEST – WATER CONTENT METHOD VERIFIED**
- **SMART FOUNDATIONS = ADJUSTABLE SOLUTION**